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Abstract

Work over the last 20 years has demonstrated a gravity bias in toddlers – when an object is dropped into a curved tube they will frequently search at a point immediately beneath the entry of the tube rather than in the object's actual location. The current study tested 2- to 3½-year-olds' (*N* = 88) gravity bias under consideration of object weight. They were tested either with a heavy or a light ball, and they either had information about one of the balls only or both. Evaluating their first search behaviour showed participants generally displayed the same age trends as other studies had demonstrated, with older toddlers passing more advanced task levels by being able to locate objects in the correct location. Object weight appeared to have no particular impact on the direction of these trends. However, where weight was accessible as relative information, toddlers were younger at passing and older at failing levels, though only significantly so from around 3 years onwards. When they failed levels, toddlers made significantly more gravity errors with the heavy ball when they had information about both balls, and more correct choices with the light ball. As a whole, the findings suggest that non-visual object variables, such as weight, impact young children's search behaviours in the gravity task, but only if these variables are presented in relation to other objects. This relational information has the potential to enhance or diminish the gravity bias.

Key words: Gravity bias; object weight.

Introduction

Between 2 and 4 years of age toddlers exhibit a so-called gravity bias in their motoric search behaviours (Hood, 1995, 1998; Hood, Carey, & Prasada, 2000; Hood, Wilson, & Dyson, 2006; Jaswal et al., 2014; Lee & Kuhlmeier, 2013). When an object is dropped into a curved tube, toddlers frequently navigate their manual search towards a location directly beneath the point at which the object has been dropped, rather than towards the actual location to which the curved tube has transported the object. In doing so, they demonstrate a tendency to prefer a location aligned with the direction of gravitational attraction. Various other studies have gone on to demonstrate that this gravity bias can be influenced by providing additional information through testimony, music, or specific visualisation strategies (Bascandziev & Harris, 2010; Bascandziev, Powell, Harris, & Carey, 2016; Iulianetti, 2016; Joh, Jaswal, & Keen, 2011) or through apparatus manipulations (Bascandziev & Harris, 2011; Huang & Lin, 2015; Joh & Spivey, 2012). However, no studies appear to examine the role of the objects involved and whether manipulations of object variables, such as their shape, size or weight, have any impact on the gravity bias. The present study aimed to address this.

A number of studies have been able to demonstrate that by the end of their first year, infants are able to use relational information about objects in a range of situations. For example, they are able to draw conclusions about how objects would be impacted in different ways due to their relative size. Infants appear to understand when an item is too big for a container even though a smaller item fit (Aguiar & Baillargeon, 2003; Hespos & Baillargeon, 2001; Wang & Baillargeon, 2008). They seem to understand that when a medium sized ball can cause another ball to roll a certain distance following collision, a bigger ball should cause the same ball to roll farther, but a smaller ball should cause it to roll a shorter distance (Kotovsky & Baillargeon, 1998; Wang, Kaufmann, & Baillargeon, 2003). Infants even expect physical size to contribute to events underpinned by social dominance (Thomsen, Frankenhuis, Ingold-Smith, & Carey, 2011).

However, object size is a variable that can be perceived through visual means and does not require an explicit manual engagement with the objects. What about non-visual variables? Young children use a range of visual and non-visual variables in their reasoning about dynamic events, including size (Hast & Howe, 2012), but weight appears to be a far more prominent one. Repeatedly, studies have demonstrated that during middle childhood, children reason about downward motion – either falling or moving down an incline – by directly drawing on the *relative* heaviness or lightness of objects (Chinn & Malhotra, 2002; Hast, 2016; Hast & Howe, 2015, 2017; Nachtigall, 1982; Sequeira & Leite, 1991; van Hise, 1988). So by around 4 or 5 years of age, weight certainly matters. However, it appears to matter in a way that misaligns children's conceptions from accepted scientific views about downward motion, frequently interfering with instruction at the formal education level – a challenge stemming from the deep entrenchment of such ideas (see e.g. Duit, Treagust, & Widodo, 2013).

But when does this involvement of weight in understanding motion events begin? Even within their first year, infants seem to at least rudimentarily appreciate object weight differences (Gottwald & Gredebäck, 2015; Hauf & Paulus, 2011; Hauf, Paulus, & Baillargeon, 2012; Molina & Jouen, 2003; Molina, Guimpel, & Jouen, 2006; Paulus & Hauf, 2011), so an understanding of weight as a concept appears early in development. Does it interfere with behaviour in tasks such as the one typically resulting in a gravity bias? If so, when does it do this, and might this indicate a starting point for the misalignment noted above? To examine this, the present study evaluated children who should already understand relative weight but who are younger than those who are known to show weight-related conceptions that deviate from scientific conceptions. Because this approximate age range of 1 to 4 years coincides with the gravity bias, it was seen as a useful task to explore this issue by exploring at what age different levels of task difficulty are failed or passed, and how the proportion of gravity-related search errors changes.

Three hypotheses were formulated around the potential impact of object weight and relational versus non-relational object information on the age at which toddlers can correctly predict the results of different configurations of the tubes in the gravity task. Firstly, if weight alone matters, then search errors and age would be impacted by object weight, regardless of whether objects are presented alone or in relation to one another. Secondly, if simply having access to two objects matters, regardless of any particular differences between the two objects, then search errors and age should be guided by this relational nature alone. Thirdly, if relative weight matters such that neither weight nor simple relational nature matter, then their interaction should impact search errors and age.

Method

Participants

A total of 88 toddlers (46 boys) aged 24 to 42 months (*M* = 32.8 months) took part in the study. This age range was selected because it is during this time that children are prone to making errors in the gravity task, and the errors were of particular interest. The toddlers were recruited from nurseries and pre-schools in LOCATION. An additional 5 children did not complete the task and their data could not be included in the analysis. Each of the four conditions outlined below had the same number of children who were matched by age, producing similar means and ranges in all four conditions.

Design and materials

Similar to the original study by Hood (1995) and subsequent studies, a wooden apparatus was constructed (see Figure 1). The apparatus consisted of a rectangular box at the bottom (10 cm high, 30 cm wide, 10 cm deep) with three drawers (each 8 cm high, 8 cm wide, 8 cm deep). Each drawer was padded on the inside to minimise sounds of the balls falling into them, which could otherwise have facilitated the children's search behaviour through provision of additional auditory cues. The top of the box had three openings of 5 cm diameter each, which were spaced so that each opening centre was 9.5 cm from the next and each centred on the drawers below. Two vertical boards (40 cm high, 10 cm wide) supported a horizontal board (30 cm high, 10 cm wide), which also had three openings of same measurements as the box. Opaque flexible tubes with 5 cm diameter were used to create pathways between the top and bottom openings. The tubes could be removed and they maintained connection by friction when inserted into the apparatus.

[insert figure 1 here]

In total, there were three possible testing levels, and the tubes could be arranged in different combinations according to difficulty level. At Level 1, the tube followed four different paths: A2 (as seen in Figure 1 left), B3, C2, and B1. During testing at this level, every combination was used with each participant but in such an order that entry and exit were both always different on two consecutive trials. The first in the order was repeated, unless it did not adhere to the entry-exit order rule, to produce a sequence of five trials. At Level 2, the tubes followed four different combination paths: A2-C1 (as seen in Figure 1 middle), A2-B1, B3-C2, and C2-A3. Other combinations were not used at this level as they do not typically lead to a gravity bias (cf. Hood, 1995). The first tube in each combination was the one into which the ball was dropped. During testing at this level, again every combination was used with each participant but in such an order that entry and exit were both always different on two consecutive trials. Again the first in the order was repeated, unless it did not adhere to the entry-exit order rule, to produce a sequence of five trials. At Level 3, the tubes followed two different arrangements: A2-B3-C1 (as seen in Figure 1 right) and C2-B1-A3. Within each combination the ball could be dropped into each entry, producing six pathways in total. During testing at this level, each participant experienced five of the six, in such an order that entry and exit were both always different on two consecutive trials.

Two test balls were used. One was a yellow table tennis ball of 4 cm diameter and weighing 3 g (referred to as the *light* ball). The other was a dark green glass marble of same diameter but weighing 75 g (referred to as the *heavy* ball). Toddlers were selected to take part in one of two main groups. In the *relational* (R) condition, toddlers were familiarised with both the heavy and the light ball. In the *non-relational* (NR) condition, toddlers were only familiarised with one ball. Toddlers were then further divided according to whether they were tested with the heavy ball (H) or the light ball (L). This resulted in four conditions based on all combinations of R and NR with H and L. In addition, a black rubber ball of 4 cm diameter and weighing 25 g was used as a practice ball.

Procedure

The apparatus was set up in a quiet area in the participating schools. The toddlers and a teaching assistant were invited to the area, and the toddlers were told that the researcher would be playing a game with them. The teaching assistants were asked to remain present in the testing area, typically behind the toddlers. This was to make the toddlers feel more at ease, and they were asked to encourage the toddlers to search, if necessary. However, they were instructed not to guide the toddlers towards any specific location either through pointing, looking, or verbal expression. In an initial acclimatisation phase, the toddlers were given a few minutes to freely examine the individual components of the apparatus. If during this time the toddlers did not open all three drawers by themselves, the researcher demonstrated this for them and encouraged them to open them, too. After this, the researcher drew the toddlers' attention to the tubes. The toddlers were first shown that the tubes could be detached from the apparatus, and they were then shown that the tubes were hollow. The researcher produced the practice ball and held one of the tubes at a downward angle of approximately 45 degrees. The practice ball was then released into the tube by the researcher or the teaching assistant, but not by the toddlers. This was done to avoid providing the toddlers with any additional relational weight information, especially in the NR conditions.

The practice ball was then removed. Following Hood (1995), the first tube was fitted into the apparatus. In the NR conditions, the researcher produced either the table tennis ball or the marble and handed it to the toddlers, who were given time to explore it manually. In the R conditions, both balls were presented simultaneously for manual exploration, after which the non-test ball was then placed to the side but remained in view of the toddlers. The researcher then took the test ball. The toddlers' attention was drawn to the ball and they watched it being dropped into the tube. The toddlers were then encouraged to find the ball. They were allowed to search until they had retrieved the ball, but only the first search where a drawer was opened was recorded by the researcher. This process was repeated four times, with a different tube arrangement on each trial by detaching and reconnecting the tube, which was done in view of the toddlers. If toddlers passed a level by correctly searching for the object on at least four out of five trials (cf. Hood, 1995), a further tube was inserted into the apparatus and the process was repeated. If toddlers did not pass a level, the procedure was finished.

Scoring and analysis

Manual searches on each trial were coded according to the three possible outcomes (correct, gravity error, non-gravity incorrect), with a maximum obtainable score of 5 for each code at each attempted level. Toddlers were grouped according to whether they had failed the first level (*L1F*), passed the first level but not the second (*L1P*), passed the second level but not the third (*L2P*), or passed the third (*L3P*). Only two of the toddlers passed Level 3. Their data were not included in any statistical analyses but are discussed in relation to age and condition factors. Gender and tube arrangement were analysed but showed no significant effects, so are not discussed further.

Results

Age trends

Table 1 shows mean ages for each level and condition. A 3 (performance: L1F, L1P, L2P) x 4 (condition: NRH, NRL, RH, RL) analysis of variance revealed a significant main effect for performance, $F(2, 74) = 192.73$, $p < .001$, $\eta^2 = .84$, indicating that participants who achieved higher task levels were older. Post hoc Bonferroni tests showed that all level groups were significantly different from each other in age. There was also a significant main effect for condition, $F(3, 74) = 3.03$, $p < .05$, $\eta^2 = .11$. However, a post hoc Bonferroni evaluation revealed that the only significant age trend difference was between the two R conditions ($p <$ .05).

[insert table 1 here]

The mean age of the L1F group was 27.1 months (SD = 1.77), with no significant differences between the conditions. For the L1P group, the mean age was 34.5 months (SD = 2.62). Here, there was a significant difference, with toddlers in the RH condition (M = 35.7 months) being significantly older than those in the RL condition (M = 33.2 months), $t(17) = 2.17$, $p < .05$. Finally, for the L2P group, the mean age was 39.9 months (SD = 1.76). Again, toddlers in the RH condition (M = 41.9 months) were significantly older than those in the RL condition (M = 38.5 months), $t(5) = 3.25$, $p < .05$. The two L3P toddlers were both in the RL condition, with a mean age of 41.2 months – which is, in fact, slightly below the RH mean for the previous level. Further research would be needed to try and address particularly the L3P group, but it seems clear that there is a divergent trend whereby the R groups are drifting apart. While the two NR conditions did not differ significantly from one another in their age trends, they do reflect similar trends noted in past research (see e.g. Figure 1 in Hood, 1995) and suggest that the balls simply being of different weight did not seem to have any impact on ages at passing levels unless they were presented in relation to one another, and only at higher task levels.

Gravity errors when failing levels

Of further interest was whether the proportion of gravity errors would be impacted by relational weight information. Figure 2 shows the mean scores for search behaviour types in each condition. Using a chance level of 1.67 errors out of 5 attempts, it was found that regardless of which task level was failed, participants made significantly more gravity errors (M = 3.13, SD = 0.98) – almost twice as many – than might be expected if they had merely performed at chance level, $t(85) = 13.80$, $p < .001$. This was a significantly higher mean score than for both correct searches (M = 1.41, SD = 0.96), $t(85) = 8.62$, $p < .001$, and non-gravity incorrect searches (M = 0.47, SD = 0.59), $t(85) = 19.02$, $p < .001$.

[insert figure 2 here]

A 3 x 4 analysis of variance subsequently showed no significant main effect for performance, suggesting that failure at passing a task level did not vary by gravity errors. However, there was a significant main effect for condition, $F(3, 74) = 8.13$, $p < .001$, $\eta^2 = .25$. Post hoc Bonferroni tests revealed a significant difference between the two R conditions ($p < .001$), with more gravity errors made for the heavy ball (M = 3.90) than for the light ball (M = 2.37). There was also a significant difference between the two H conditions ($p < .05$), with more errors made if the heavy ball had been presented in relation to the light ball. Conversely, correct choices when failing levels (M = 1.41, SD = 0.96) were significantly below chance regardless of condition, $t(85) = 2.53$, $p < .05$. However, rather than simply making more incorrect choices in conditions where fewer gravity errors were made, a 3 x 4 analysis of variance again showed no significant main effect for performance but a significant main effect for condition, $F(3, 74) = 9.38$, $p < .001$, $\eta^2 = .28$. Post hoc evaluations showed that significantly more correct searches were made in the RL condition (M = 2.29) than in any of the other three conditions. And again it is worth noting that both L3P participants were in the RL condition. Overall, these findings, too, suggest that absolute weight has no influence on children's search behaviour, but relative weight does influence such behaviour.

Discussion

The present study aimed to evaluate the potential impact of information about object weight on 2- to 3½-year-olds' success and failure at search tasks often influenced by gravity error. With increasing age toddlers were more competent in their search performance, passing the one-tube arrangement shortly before their third birthday and the two-tube arrangement around six months later. This trend is quite in line with other studies evaluating the gravity bias (e.g. Hood, 1995). At first sight, object weight does not appear to impact toddlers' search behaviour, since it made no difference whether a heavy or a light object was used per se. However, once objects are explicitly placed in relation to each other, the outcomes begin to diverge based on the information that has been made available. Relative heaviness appears to lead to passing search levels at a slightly older age and to making more gravity errors than when not having relational information available, whereas relative lightness seems to have the inverse impact on search behaviour. More crucially, this pattern only seems to emerge closer to three years rather than earlier.

An initial explanation to the key differences between groups might be offered through the role of interference in executive functions (cf. Lee & Kuhlmeier, 2013). Young children's search behaviour is known to be informed by other factors, such as testimony, music, or specific visualisation strategies, either supporting or hindering that behaviour (Bascandziev & Harris, 2010, 2011; Bascandziev et al., 2016; Huang & Lin, 2015; Iulianetti, 2016; Joh et al., 2011; Joh & Spivey, 2012). The toddlers in the present study were given additional information to process in the R conditions that they did not have to process in the NR conditions, and it would therefore seem reasonable to suggest that this additional information might have interfered with their searching. However, it does not seem to be a categorical case whereby additional information interferes in a negative manner, since relative lightness actually seems to *support* the processing and overcoming the bias. A simple focus on interference can therefore not provide a satisfactory answer.

The differences might also be linked to children's representational momentum (Gresham, 2012; Haddad, Chen, & Keen, 2011; Perry, Smith, & Hockema, 2008; Taylor & Jakobson, 2010), or to research around naïve impetus (Kozhevnikov & Hegarty, 2001; White, 2012). Search behaviour is seen to be guided by beliefs based on certain conditions such as slope angle. Objects are anticipated to have more momentum if a slope is steeper (cf. Bertamini, 1993), and the objects are expected to be found in a location farther from where it actually is – even if this means for the object passing through a barrier. Quite similarly, slightly older children anticipate speed *change* during the early phase of a trajectory but not beyond, reducing this to a short but intensive effort (Hast & Howe, 2013; Nachtigall, 1982; Piaget, 1970). What is shown in the present study could be taken as a precursor to this. Relational information, which would make the heaviness more salient, might lead to a representation of a ball being dropped into a tube in such a way that it possesses the necessary momentum to fall straight down, regardless of the pathway, and quite possibly at a greater speed as well – more so than if this relation did not exist. Conversely, the relative lightness might intuitively slow the ball down, therefore being more likely to be guided by the shape of the tube. This latter explanation would be supported by studies with adults on a range of physical phenomena, including representational momentum (e.g. Hubbard, 2005) or a Galileo bias (e.g. Oberle, McBeath, Madigan, & Sugar, 2005).

However, although the gravity error is already evident amongst the youngest toddlers tested in the present study, object weight appears to play little role, if any, in their search behaviours. Why does the pattern found here seem to indicate a differentiation at around 3 years of age rather than sooner, or indeed later? One explanation may come from other studies involving children and their understanding of relative weight. Povinelli, Vonk and

Castille (2012), for instance, cite examples of 3-year-old children referring to heavy balls as being “big” – even when they were actually the same size as lighter ones – and “strong”, without making reference to their weight. This abstraction of weight is even applied to invisible situations through continued representation in unobservable states. So although the toddlers in the present study could no longer see the test ball once it had been dropped into a tube, the continued representation of that object and its weight impacts their search behaviour. This is worth examining further, as other studies have shown discrepancies between looking and reaching in search tasks with young children, including the gravity bias (e.g. Baker, Gjersoe, Sibielska-Woch, Leslie, & Hood, 2011; Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Lee & Kuhlmeier, 2013; Haddad, Kloos, & Keen, 2008; Hood, Cole-Davies, & Dias, 2003; Hood et al., 2006; Keen et al., 2008; Mash, Novak, Berthier, & Keen, 2006). Evaluating whether such discrepancy also exists in the current context could provide more detailed insight into whether the gravity bias is guided by weight and to highlight the salience of this variable. This would be consistent with other work that addresses the importance of weight in displacement (see e.g. Hubbard, 1997, 2005). For instance, 2-year-olds’ manual search may not be significantly impacted by relational weight but perhaps such an impact is evident in their gaze. Contrarily, perhaps older toddlers’ weight-related bias is only present in their manual search but not their gaze.

Relatedly, the size-weight illusion may also play a role in trying to explain the age differences here. When objects are of different size but their weights are identical, the smaller object, in an illusory effect, feels heavier than the larger object. Children as young as two years of age experience this illusion (Buckingham, 2014). In the present case, the two balls were the same size. This could have created a sense of more similar weights between the two. Buckingham (2014) further notes that the magnitude of the size-weight illusion actually decreases throughout childhood, and so it is possible that younger toddlers may have perceived the two balls to be relatively similar in weight because of the same size and therefore their search behaviour would not have been guided by object weight differences – which the results indicated. Conversely, with the slightly older toddlers this illusion may have had less impact and therefore they would have been more likely to be guided by the true relative weights. Further research would need to examine this.

In sum, although even preverbal infants take into account relational information about objects to draw conclusions about events (Aguiar & Baillargeon, 2003; Hespos & Baillargeon, 2001; Kotovsky & Baillargeon, 1998; Thomsen et al., 2011; Wang & Baillargeon, 2008; Wang et al., 2003) this study was particularly interested in in examining whether a non-visual variable such as relative weight is incorporated into processing of event outcomes. The findings from the current study have shown that by 3 years of age weight matters – not only the relative heaviness of an object, but even relative lightness. This consequentially also means that force matters this early, and future research would do well to address the relative importance of dynamic versus kinematic information in representations. The findings might furthermore give rise to explanations regarding weight-related object motion preconceptions that are misaligned against accepted scientific views (Hast, 2016; Hast & Howe, 2015, 2017; Chinn & Malhotra, 2002; Nachtigall, 1982; Sequeira & Leite, 1991; van Hise, 1988), particularly in trying to understand when this misalignment emerges, though further research would be needed to evaluate this in more detail.

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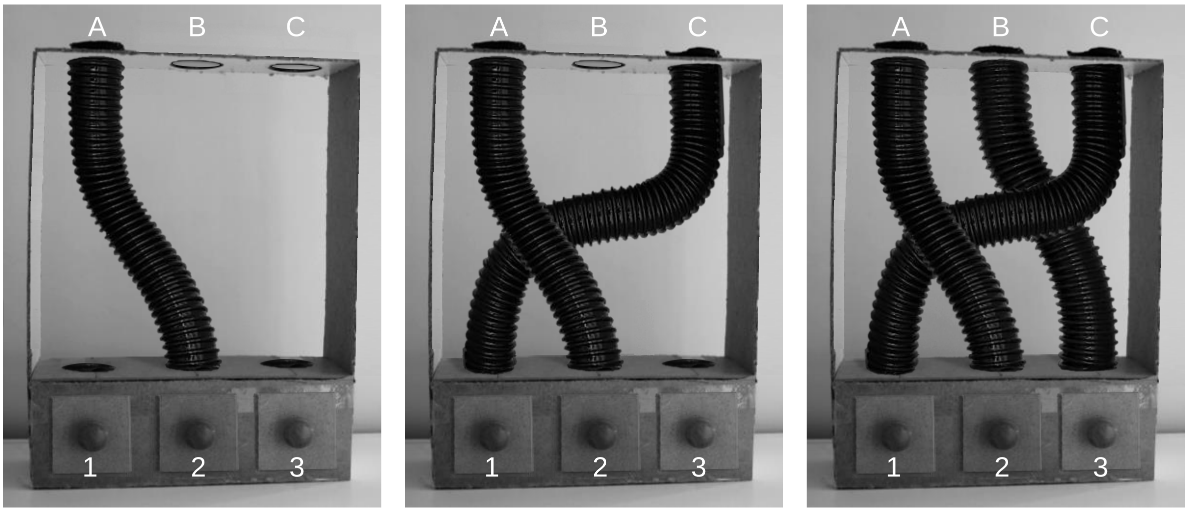

Figure 1. Apparatus with tubes attached in sample combinations for Level 1 (left), Level 2 (middle) and Level 3 (right). Letters at the top in each image refer to tube entry points, numbers at the bottom to tube exits.

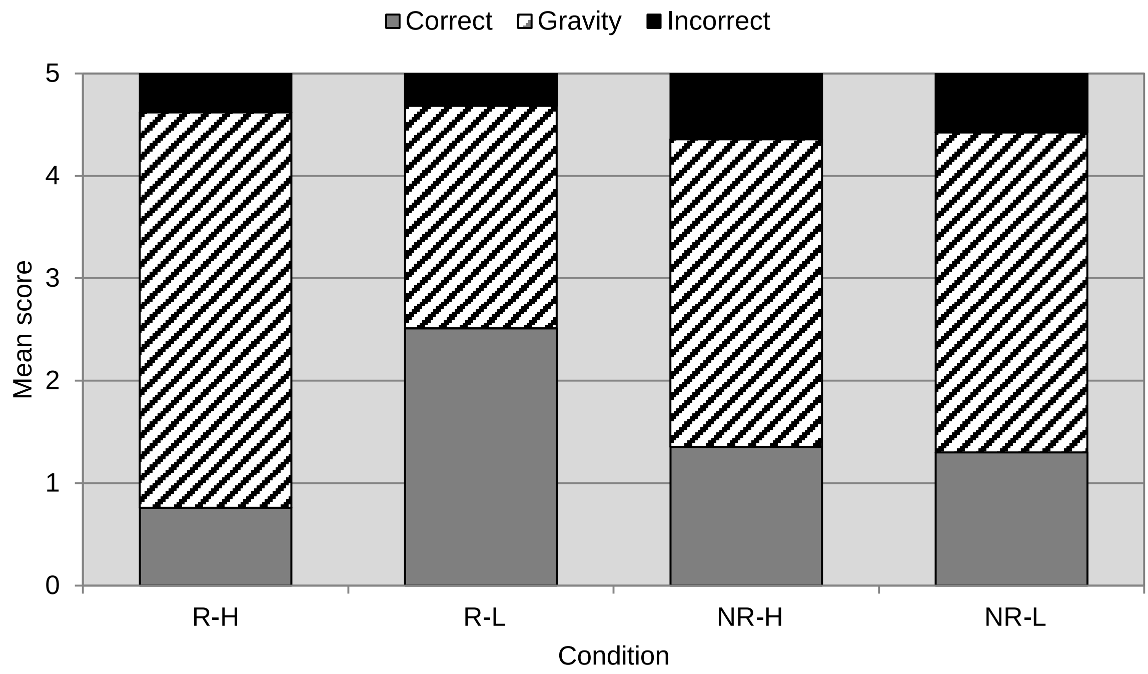

Figure 2. Mean number of first search outcomes for each condition.

Table 1. Mean ages in months for each condition and level.

	Relational		**Non-relational**	
	Heavy	Light	Heavy	Light
Level 1 fail	27.8	26.7	27.1	26.9
Level 1 pass	35.7	33.2	34.3	34.5
Level 2 pass	41.9	38.5	40.5	40.2
Level 3 pass	-	41.2	-	-